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Method and arrangement for controlling the power supply of a mobile device comprising at least one electric drive motor and a hybrid power system containing a fuel cell system and a dynamic power system

The invention relates to a method and an arrangement for controlling the power supply of a mobile device having at least one electric drive motor and a hybrid power supply system which has a fuel cell system and a dynamic power system, wherein the electrical outputs of the fuel cell system are connected to one side of a power converter whose other side feeds the drive motor which is controlled by a motor control unit, and wherein the dynamic power system has a storage battery which is connected to one side of a d.c./d.c. transformer whose other side is connected to the electrical outputs of the fuel cell system and to one side of the power converter.

A power supply system in an electric vehicle which has a fuel cell and a storage battery which can be connected in parallel with it is known. The electrical outputs of the fuel cell are connected to a motor for driving the vehicle and to a d.c./d.c. transformer to which auxiliary machines in the vehicle are connected. The power supply system contains a residual charge monitoring device for measuring the residual charge of the storage battery. The residual charge monitoring device senses the residual charge in the storage battery at the time of the stopping process of the power supply system. If the residue charge is below a predefinable limiting value, the fuel cell charges the storage battery to the limiting value. The power supply system is not stopped until then (DE 197 31 250 A1).

A hybrid drive concept for fuel cell vehicles which have, as a power source, a fuel cell which feeds an electric drive motor is known. The respective vehicle contains a power accumulator and electrical secondary loads. Two separate circuits which are provided with switching devices for optionally connecting the electric drive motor and the secondary load to the fuel cell or to the power accumulator and a switchable connection between the fuel cell and the power accumulator are present in the vehicle (DE 198 10 467 C1).

A fuel cell system is also known which has a fuel tank, a reformer, a fuel cell, a d.c./d.c. transformer which is connected to the electrical outputs of the fuel cell and a load which is connected to the d.c./d.c. transformer and in parallel with which a storage battery is connected. The fuel cell system contains a control unit with which the residual charge of the storage battery is sensed. The control unit ensures that the storage battery is charged to a predefinable charge state in the shortest possible time (EP 0334 47 474 B1).

Finally, a power supply system is known which has a fuel cell, a d.c./d.c. transformer which is connected to the electrical outputs of the fuel cell, and a load which is connected to the outputs of the d.c./d.c. transformer. A storage battery is connected in parallel with the load. A control unit regulates the current flowing via the d.c./d.c. transformer in such a way that the output voltage of the fuel cell remains within a predefined range (US 5714 874).

The invention is based on the problem of specifying, for the power supply of a mobile device having at least one electric drive motor and a hybrid power system composed of a fuel cell system and a dynamic power system, a method and an arrangement with which the

hybrid power system can be controlled in an optimum way in terms of the respectively required dynamics, with adaptation to the parameters and/or operating states.

The object is achieved according to the invention with a method of the type described at the beginning in that signals which are generated by a signal transmitter for requesting the setpoint power of the drive motor, a signal which is output by an operating mode switch with a plurality of selectable settings which are each assigned to different types of dynamic behavior of the device, emitted values of a power sensor for the output current and emitted values of a voltage sensor for the output voltage of the fuel cell and emitted values of a sensor for the velocity of the device are processed in order to determine the power components in the requested setpoint power which are to be provided by the fuel cell system and by the dynamic power system, in such a way that when there is a change in the setpoint power the difference between the partial power which can be generated by the fuel cell system with a delay according to the transition function and the setpoint power is generated by the storage battery of the dynamic power system by applying corresponding setpoint values to the d.c./d.c. transformer, with reference to the power of the drive motor which has already been output and the power of the fuel cell system which has already been generated as well as the velocity of the device, taking into account the selected type of dynamic behavior and the different transition functions of the fuel cell system and of the dynamic power system. On the basis of the knowledge of the power demand of the mobile device, which respectively depends on the setpoint value of the torque, the setting element and the measured values of the sensors and which is calculated from the signals, position sensors and measured values, the power demand can be adapted to the fuel cell system in a suitable way, i.e. with a favorable efficiency and/or favorable

time behavior, while the storage battery supplies the power contribution for rapid dynamics of the mobile device.

In the case of a sudden increase or decrease in the setpoint power, the increase or decrease in the current flowing out of or into the storage battery via the d.c./d.c. converter - said increase or decrease being necessary for the increase or decrease in the additional power - is limited in particular to a maximum prescribable discharge current or a maximum prescribable charge current. The maximum discharge current or charge current is obtained, for example, from the type of the storage battery used.

In one preferred embodiment, from a vehicle control unit of the mobile device load current values of the further loads in the device are superimposed on the power demand values for the drive motor which are determined from the setpoint power and fed, with a charge current value generated when necessary by a battery management system, to a power control unit with limitation to a predeterminable fuel cell maximum power value of a power control unit, to which power control unit device for velocity values, torque setpoint values from a setting element, battery charge state values and the setting of the operating mode selector switch are fed to the mobile device, and which calculates, as a function of the fed values, the values of the overall power demand and of the power demand which is to be contributed by the fuel cell system taking into account its inertia behavior and the selected dynamic behavior, and outputs corresponding setpoint values to the actuating elements of the fuel cell system, and in that in each case the values of the current which is output by the fuel cell is determined, subtracted from the value of the current required by the drive motor, and are fed as current setpoint values to the d.c./d.c. transformer with limitation to a maximum specifiable

discharge current or charge current of the storage battery. The power control unit detects, by reference to the values fed to it, the operating mode and the operating state of the mobile device and concludes therefrom the type of current contribution which the fuel cell system has to make for the power converter and the auxiliary drive, wherein the storage battery provides the current contributions for the high-speed dynamic demand levels. The method according to the invention permits very rapid setting of the current to be applied in order to achieve satisfactory driving dynamics, by the d.c./d.c. transformer.

In a further favorable embodiment there is provision that the sum of the value of the current which is respectively drawn from the drive motor via the power converter and values of the currents which are drawn from the other loads of the device are subtracted from the value of the current which is output by the fuel cell, and when a maximum predefinable value of the discharge current of the storage battery is reached it is limited to its discharge current, and in that the result of the difference between the values of the currents which are drawn from the further loads is added to the value of the available fuel cell current and signaled to the control unit of the device as an available value of the current. The available current is a dynamic current in response to the demand for a current. The fuel cell system meters the amount of fuel sufficient for this current to be drawn. The control unit is therefore capable of matching the current demands made of the mobile device to the respective available values of the current.

It is particularly advantageous to simulate the transition function of the fuel cell system as a controlled system using a memory element of the n-th order, to apply the torque setpoint value which is output by the vehicle control unit of the mobile device

to the memory element and to a control unit for the dynamic power system and additionally to feed the values generated according to the transition function of the controlled system to the control unit and to feed the current which is to be applied by the dynamic power system as a current setpoint value to the d.c./d.c. transformer by the control unit by means of a limiter element with a ramp, the gradient of which can be set to at least two values as a function of control signals from the device. In this embodiment, particularly good overall dynamics are achieved. The efficiency of the dynamic power system is exploited here to an optimum degree. For example, during rapid starting of the mobile device, i.e. at the start of starting and with the low power of the fuel cell system, the power is applied by the dynamic power system so that the large torque which is necessary to accelerate the device is rapidly available. At high rotational speeds, the power for the acceleration in order to reach a high rotational speed is output by the dynamic power system. A sliding transition of the power contributions of the fuel cell and power system is achieved by means of the power control unit.

In order to achieve high acceleration it is expedient if during the duration of an acceleration process of the device, during which the setpoint torque is determined by the vehicle control unit by pilot control and a maximum current for the generation of the setpoint torque is determined from a characteristic diagram with the torque as a function of the maximum current and the rotational speed, the difference between the current which is generated by the fuel cell system during the acceleration process and the overall current which is required by the dynamic power system according to the characteristic diagram in order to achieve the high acceleration is generated. With this embodiment, particularly good longitudinal dynamics are generated in a mobile device, in particular an electric

vehicle, since the dynamic power system is utilized to an optimum degree.

In order to utilize the power of the mobile device satisfactorily, the excess energy occurring when the load of the drive motor is reduced is recovered and stored in the dynamic power system.

When there is a negative load jump, i.e. owing to a corresponding change in the actuating element for the power to be output by the drive motor, the power converter is set to reverse mode. The d.c./d.c. transformer is also set in such a way that it feeds current into the storage battery and charges it. The charge current is determined by the charge controller which controls the charge currents across the d.c./d.c. transformer as a function of the charge state of the storage battery. When there is a reduction in the setpoint torque to be output by the drive motor as a result of the presetting of a lower torque setpoint value, the current which is necessary for the lower torque is preferably determined from the characteristic diagram, and with reference to the respective load state of the fuel cell system given the presetting of the lower torque setpoint value and the storage capacity of the storage battery the latter is charged with the maximum permissible charge current by means of the d.c./d.c. transformer after the reversal of the flow of current in the power converter, and the fuel cell system is set to the current which is necessary for the lower setpoint torque. This measure avoids the risk of overheating of the fuel cell system.

In another preferred embodiment the direction of the supply of combustion gas and air to the fuel cell is reversed periodically, and in which case during the reversal of the supply of gas a current pulse which is matched to the instantaneous output of current of the fuel cell system and/or of the dynamic power system

directly before the changeover is fed in to the power converter by the dynamic power system via the d.c./d.c. transformer. This avoids undesired fluctuations in the drive torque.

It is also expedient if the output voltage of the fuel cell system is monitored to determine when a voltage limiting value which is permissible for satisfactory operation is reached or undershot, and wherein when the voltage limiting value is reached, the voltage in the power system which is connected to the output of the fuel cell is regulated to at least the permissible limiting value by feeding in current via the d.c./d.c. transformer. In particular, the load situation of the power supply system during the intervention of the regulating process and the frequency of intervention of the voltage regulating process during the operation of the power supply system are registered, and in which case after a predefinable number of interventions have been exceeded the dynamics are limited by reducing the rate of increase in the current of the fuel cell system and/or the dynamic power system and the magnitude of the power which is output.

It is favorable to limit the rate of increase in the output power of the fuel cell system given sufficient storage battery charge when the torque setpoint value is increased and for the current which is necessary to output the torque setpoint value to be fed by the dynamic power system during the increase in the output power. In this context it is advantageous for operation of the power supply system with a high level of efficiency to approach the load state of the fuel cell system which is demanded by the torque setpoint value by means of a ramp with a low rate of increase.

It is particularly expedient if at least three operating modes for the drive motor can be set by means of the operating mode selector switch, one operating

mode of which is aimed at a high level of dynamics of the mobile device, a second of which is aimed at a low level of dynamics with high efficiency and a third of which is aimed at a stop and go operating mode, and in that when accelerations occur in the stop and go operating mode currents are generated for the drive motor by the dynamic power system and stored therein during braking.

The portion of the current to be applied by the dynamic power system which is formed by the current necessary to generate a requested drive power in particular with the respectively existing actual value of the current consumed by the mobile device and the current available from the fuel cell system is determined.

Given reduced power of the fuel cell system, an emergency operating mode of the power supply system is preferably ensured by a voltage regulating mode in the high voltage power system by means of the d.c./d.c. transformer and by feeding in current from the storage battery.

Given an arrangement of the type described at the beginning, the problem is solved according to the invention in that a vehicle control unit which is connected to a velocity sensor of the mobile device and to a signal transmitter for a setpoint torque to be generated by the drive motor is provided for setting the setpoint torque of an motor control unit and for determining the current setpoint values for the mobile device which are stored in a characteristic diagram for torque values and rotational speed values, in that the vehicle control unit is connected to the power control unit which is connected to the fuel cell system, a battery management system for the storage battery and to the d.c./d.c. transformer, in that the current which is output by the fuel cell of the fuel cell system is measured and is fed as a fuel cell current value to the

power control unit, in that the current of the drive motor is measured upstream of the power converter and is fed as a driving current value to the power control unit, in that the currents of the other loads are measured or calculated and fed to the power control unit as a composite current value, in that an operating mode selector switch for setting various types of dynamic behavior of the power supply system is connected to the power control unit, in that values relating to the charge state of the storage battery, from the battery management system, and values relating to the maximum prescribable charge current and discharge current are fed to a power flux controller in the power control unit, and in that the power setpoint value, the fuel cell current value, the driving current value, the composite current value, the operating mode which is set with the operating mode selector switch, the charge state value and the maximum prescribed values of the charge current and discharge current are processed in the power control unit and in the associated power flux controller with one or more programs in such a way that when there is a change in the setpoint power the difference between the partial power which can be generated by the fuel cell system with a delay according to the transition function and the setpoint power is generated by the storage battery of the dynamic power system by applying corresponding setpoint values to the d.c./d.c. transformer, with reference to the power of the drive motor which has already been output and the power of the fuel cell system which has already been generated as well as the velocity of the device, taking into account the selected type of dynamic behavior and the different transition functions of the fuel cell system and of the dynamic power system. The current which is to be contributed by the battery is determined from the vehicle current and the available current of the fuel cell, which takes only a very short time.

The invention is described in more detail below with reference to an exemplary embodiment which is illustrated in a drawing and from which further features, details and advantages emerge. In the drawing:

fig. 1 is a block circuit diagram of an arrangement for controlling the power supply of a mobile device having a fuel cell system and a dynamic power system as well as a power control unit and at least one electric drive motor,

fig. 2 is a block circuit diagram or signal flow diagram of the power control unit illustrated in fig. 1,

fig. 3 is a block circuit diagram of a model of a fuel cell system with a methanol reformer and a control unit,

fig. 4 is a diagram of the fuel cell current and of the power system current given maximum acceleration as a function of time,

fig. 5 is a diagram of the fuel cell current and of the power system current given an acceleration which is below the maximum acceleration, and

fig. 6 is a diagram of currents of the fuel cell system of the device and of the power system as a function of time in various operating states.

A mobile device, in particular a vehicle 1, contains a drive motor unit 2 which has a power converter 3 to which a motor (not illustrated in more detail), which may be an asynchronous motor, is connected. A locomotive or a forklift truck may also be provided as a mobile device. The rotational speed or torque of the motor is controlled by a motor controller 4 by means of

the power converter 3. The power converter 3 is connected at its terminals which are opposite the motor to a d.c. power system 5 which is referred to a high voltage power system and which has a voltage in the range from 250 to 450 V. In addition to the drive motor unit 2, there are other power loads (referred to as 6) in the vehicle 1. These loads are, for example, a compressor, a ventilator, a water pump, the loads of an air conditioning system and a d.c./d.c. transformer between the high voltage system and a 12 V, 24 or 42 V low voltage power system with further loads such as headlights, windshield wiper motors, window drives, indicator flasher lights etc. The d.c. power system 5 is connected to the electrical outputs (not designated in more detail) of a fuel cell system 7 with a fuel cell (not designated in more detail). The fuel cell system 7 contains elements which are known per se, such as a fuel tank with liquid fuel, for example methanol, a reformer, a water tank and a compressor as well as a fuel cell to which combustion gas is fed from the reformer and air is fed from the compressor. A fuel cell controller 8 activates the actuating elements of the fuel cell system in order to cause them to output a corresponding amount of power. A d.c./d.c. transformer 9 is also connected to the d.c. power system 5 and is designed for bidirectional operation and connected at its terminals facing away from the high voltage power system 5 to a storage battery 10 which generates, for example, a voltage of 200 V. Instead of a storage battery, a supercapacitor or some other power accumulator can also be provided.

A d.c./d.c. transformer controller 11, which sets the direction of the current of the d.c./d.c. converter and the current level which is output and can reset said transformer to a voltage regulating mode for the d.c. power system 5 is connected to the d.c./d.c. transformer 9. The storage battery 10 is connected to a battery management system 12.

A voltage sensor 13 is connected to the outputs of a fuel cell in order to measure the d.c. voltage of the d.c. power system 5. The current which is output by the fuel cell is measured by a current sensor 14. This current is designated below as a fuel cell vehicle current. The current which is drawn by the additional loads is measured using a current sensor 15 and is referred to below as an auxiliary current. The current which flows to the drive control unit 2 via the power converter 3 or is fed back from the power converter 3 is measured using a current sensor 16 and is also referred to below as the driving current. The current which flows from or to the d.c./d.c. transformer at the d.c. power system end is measured using a current sensor 17 and is referred to below as the d.c. transformer current. The voltage of the battery 10 is measured using a voltage sensor 20 which is connected to the battery management system 12. The motor controller 4 is connected to a vehicle control unit 18 via data lines which are shown by dashed lines in fig. 1. A power control unit 19 is connected via data lines (illustrated by dashed lines in fig. 1) to the vehicle control unit 18, the fuel cell controller 8, the battery management system 12 and the d.c./d.c. transformer controller 11. The voltage sensor 13 and the current sensor 14 are connected to the fuel cell controller 8. The current sensor 15 and the current sensor 16 are connected to the vehicle control unit 18. The voltage sensor 20 and the current sensor 17 are connected to the battery management system 12 which monitors all the data of the battery 10 and continuously determines the charge current of the battery 10.

The value of the fuel cell vehicle current which is measured by the current sensor 14, referred to below as $I_{BRZFahrz}$, is signaled to the power control unit 19 via the fuel cell controller 8 on data line 21. The value

of the current which is consumed by the drive motor, or if appropriate by a plurality of drive motors, at the respective time and which flows into the power converter 3 and is referred to below as $I_{Fahrzeug}$, is fed to the power control unit 19 on a data line 22. The value of the auxiliary current, referred to below as I_{Aux}, is signaled to the power control unit 19 on a data line 23 on a data line 23. On a further data line 24, the value of the current which is made available by the fuel cell, referred to below as I_{Verf} is fed to the power control unit 19. The value I_{Verf} is a limiting value and indicates how much current can be drawn via the fuel cell. This current I_{Verf} is a dynamic value in response to a current value I_{BRZAnf}, which is output by the power flux controller 38 to the actuating elements of the fuel cell system 7. The fuel cell system 7 meters the quantity of fuel which is such that this current I_{Verf} can and has to be drawn. If too much current is drawn, the fuel cell is under-supplied. If too little current is drawn, too much H_2 is generated, which damages the reformer system. I_{Verf} is thus a dynamic current which is also to be drawn. The value $I_{BRZFahrz}$ is subtracted from the value I_{Verf}, which is represented in fig. 2 by the summing point 24a. The current values $I_{Fahrzeug}$ and I_{Aux} are superimposed one on the other, which is represented in fig. 2 by a summing point 25. The value I_{Aux} is subtracted from the value I_{Verf}. This is referred to in fig. 2 by 26. The value I_{Verf} is subtracted from the sum of $I_{Fahrzeug}$ and I_{Aux} at a summing point which is referred to as 27. If the result $I_{Fahrzeug} + I_{Aux} - I_{Verf}$ is greater than a maximum prescribable, stored discharge current value of the storage battery 10, said current value, referred to $I_{Battmax1}$ is further processed in the comparator 28. The value which is passed on by the comparator 28 is fed to a further comparator 29 in which a comparison is made with a prescribable, stored maximum permissible discharge current which is referred to as $I_{Battmaxe}$ in fig. 2. The value at the output of the comparator 29 is

limited to this value if the input value is greater. The output value of the comparator 29 is superimposed on the difference I_{Verf} - I_{Aux} at a summing point 30 and results in a current value $I_{Fahrzeugverf}$, which is fed to the vehicle control unit 18. For this reason, the maximum available current value is available to the vehicle control unit 18 so that this unit does not output any higher current demand.

The vehicle control unit 18, to which the power to be output by the drive motor is signaled by a setpoint value transmitter 31, calculates a setpoint current value for the vehicle, referred to below as I_{AnsF}, from the position of the setpoint value transmitter and the rotational speed of the drive motor, measured by a sensor, from a table - stored in the trial operating mode - for the torque as a function of the current and the rotational speed, said setpoint current value being superimposed on the value I_{Aux} at a summing point 32. A battery charge controller 33 which is part of the power flux control unit 19 monitors the charge state of the storage battery 10 by means of sensors (not illustrated in more detail) and generates, when necessary, a charge current demand, referred to $I_{Ladeanf}$, as a function of the measured battery temperature and the driving style which is determined from the measured rotational speed profile per time unit. The value $I_{Ladeanf}$ is superimposed on the sum of I_{AnfF} and I_{Aux} at a summing point 34. The result which is calculated at the summing point 32 is fed to a comparator 34 which determines whether the input value is greater than a maximum prescribable, stored, dynamic fuel cell current value, referred to below as $I_{BRZDynmax}$.

If the output value of the summing point is greater than $I_{BRZDynmax}$, this value is further processed at a summing point 35 at which a current value I_{Anf} is superimposed. The value I_{Anf} is calculated by a quasi-static regulator 36. The values $I_{Fahrzeug}$, I_{Aux}, I_{Verf} and

$I_{Ladeanf}$, from which the regulator I_{Anf} calculates, are fed to the quasi-static regulator.

The sum which is formed at the summing point 35 is compared in a comparator 37 with a current minimum value, referred to below as I_{BRZmin}. This current minimum value is passed on to a variable power flux controller 38 if the result of the summing point 35 is smaller than this value.

The temperature value of the battery T_{Batt} is fed by a sensor (not illustrated) to a calculation unit 39 for limiting values of the battery current, as are the load state of the battery LZ by the battery charge controller 33 and the value of the voltage of the fuel cell U_{BZ}. The calculation unit 39 determines a maximum battery current value $I_{MaxBatt}$ from these values.

A further calculation unit 40 for the maximum fuel cell current I_{maxBRZ} receives the maximum dynamic fuel cell current value $I_{BRZDynmax}$ from a temperature sensor (not illustrated) of the fuel cell T_{BRZ}, and a previously stored maximum static value, determined, for example, by trials, of the fuel cell system $I_{BRZmaxstat}$.

The value of the charge demand $I_{Ladeanf}$, the value I_{Aux} and the values $I_{maxBatt}$ and I_{BRZmax} are fed to a calculation unit 41 which determined therefrom the value of the maximum vehicle current $I_{maxFahr}$ and feeds it to the vehicle control unit 19.

The value of the output of the comparator 20 is superimposed, at a summing point 42, on the difference between $I_{BRZFahrz}$ and I_{Verf}. The result which is determined in this way is added to the value $I_{Ladeanf}$ at a summing point 43.

The fuel cell system 7 has a flow switch compensation function with which the power dip when the direction of

the gas supply to the fuel cell is reversed is compensated. A flow switch control unit 44 generates a current value I_{FSW} which is added to the result from the summing point 43 at a summing point 45 during the switchover period.

In order to prevent the voltage in the high voltage power system 5 dropping to a value which is dangerous for the operation of the fuel cell, a voltage regulating unit 46 is provided with which the voltage of the high voltage power system is monitored to determine whether a lower limiting value is reached or undershot. As soon as this limiting value is reached or undershot, the voltage regulating unit 46 outputs a value I_{REG} which is superimposed on the result of the output of the summing point 45 at a summing point 47. The value at the output of the summing point 47 is fed to a comparator 48 which limits this value to the maximum set charge current if the input current is larger.

The output value of the comparator 48 is fed to a further comparator 49 which limits the value to the maximum set discharge current $I_{Battmaxe}$ if the input value is higher. The output value of the comparator 48 is fed as a current setpoint value $I_{d.c./d.c.}$ to the d.c./d.c. transformer controller 11.

The variable power flux controller 38, an essential component of the power control unit 19, receives measured values of the vehicle velocity V_F, of the setpoint value transmitter 31 relating to the setpoint torque M_{soll} demanded by the drive motor, the value I_{AnfF} from the vehicle control unit 18 and the battery charge state from the battery charge controller 33. Furthermore, an operating mode selector switch composed of a series of switches 50, 51, 52, with which a specific operating mode of the dynamic behavior of the vehicle 1 can be set manually is present in the

vehicle 1. The switched positions of the switches 50, 51, 52 are fed to the variable power flux controller 38. In addition, a signal which relates to an antilock braking operation and signals this to the variable power flux controller 38 is fed to the variable power flux controller 38 by the vehicle control unit 18. The power flux controller 38 processes these values and outputs a value I_{BRZAnf} to the actuating elements of the fuel cell system 7.

The storage battery 10 with the battery management system 12 and the d.c./d.c. transformer 9 with the d.c./d.c. transformer controller 11 form a dynamic power system 53. A model 54 of the fuel cell system 7 with the methanol reformer and the associated components which are known per se is stored in the variable power flux controller 38. The model 54 has a reaction-free memory element of the n-th order PTn_1. In each case the torque setpoint value is applied to the input 56 of the model 54 by the vehicle control unit 18. The time constant of the memory element PTn_1 is set by an input 55 of the model 54. The memory element PTn_1 is also designated by a delay element. The input 56 and the output of the memory element PTn_1 are connected to inputs of a control unit 57 which influences the behavior of the dynamic power system 53.

The control unit 57 is connected at the output end to a memory element of the n-th order PTn_2 which has a further input which is connected to a changeover switch 58, which is set by the vehicle control unit 18. The setting depends whether or not the vehicle 1 is in the antilock braking system mode. Two different time constants are set in the memory element PTn_2 by means of the changeover switch 58 by means of the inputs 100 and 101, one of which is set to the dynamics in the normal operating mode of the dynamic power system 53 and the other of which is set to the antilock braking mode. The output of the memory element PTn_1 indicates

the "slow" reaction of the fuel cell system. The output of the memory element PTn_2 indicates the "rapid" reaction of the dynamic power system 53.

The output values of the memory element PTn_1 and PTn_2 are superimposed one on the other at a summing point 59 which indicates the sum of the "rapid" and "slow" reactions. The output values of the memory elements PTn_1 and PTn_2 and of the summing point are processed by the variable power flux controller 38, in which case different dynamic operating modes of the vehicle 1 are taken into account. The memory element PTn_2 limits the supply of power by the dynamic power system in terms of its dynamics and is also designated by a limiter.

In a first operating mode, which can be designated by "acceleration boost", the dynamic power system 53 is used to improve the longitudinal dynamics of the vehicle. The dynamic power system 53 is made to output power by the power control units 19 for the duration of an acceleration process, that is to say in a chronologically limited fashion, said power having an additive effect to the power generated by the fuel cell system 7. In this context, the vehicle control unit 18 controls the torque setpoint value as a function of the available current from the characteristic diagram $M_{Soll} = F(I_{max}, n)$. I_{max} is here the composite current of the fuel cell system 7 and of the dynamic power system 53.

In fig. 4, the current is illustrated in the ordinate direction as a function of the time t in the abscissa direction. It will be assumed that a setpoint value jump to the setpoint value I_{AnfF}, designated by 60 in fig. 4, takes place at the time t_1. In the "acceleration boost" operating mode, the variable power flux controller 38 demands the maximum current of the fuel cell system 7 I_{BRZMax} and the maximum current of the dynamic power system 53 $I_{BattMax}$. The fuel cell current

I_{BZ}, which is designated by 61 in fig. 4, increases to I_{BRZmax} after a transition function, which value is registered by the variable power flux controller 38 by reference to the model 54 and the dynamic power system 53 causes the current I_{Batt}, designated by 62 in fig. 4, to be output by means of the setting of the d.c./d.c. transformer 9, said current I_{Batt} increasing with the ramp which is determined by the memory element PTn_2 and remaining at the current $I_{BattMax}$ for the duration of the "acceleration boost".

Fig. 5 shows the current profile as a function of time at a setpoint value jump 53 which is smaller than the sum I_{BRZMax} + $I_{Battmax}$. The variable power flux controller 38 causes the fuel cell I_{BRZ} to output the current I_{BRZMax}. The profile of the current I_{BRZ} is designated by 64 in fig. 5. The increase takes place with the transition function of the fuel cell system. The dynamic power system 53 generates the current I_{Batt} whose profile is designated by 65 in fig. 5 and is added to the current I_{BRZ}, as a result of which the setpoint value 63 is reached more quickly. As soon as the setpoint value 63 has been reached, the fuel cell feeds in the current I_{BRZMax}, while the current I_{Batt} returns to a lower value at which it remains for the duration of the acceleration boost.

Fig. 6 shows the profile of currents I of the power supply system of the vehicle 1 and of the drive unit as a function of the time t in various operating modes such as "dynamic boost", "quasi-static operating mode" and "braking mode". It will be assumed that the vehicle control unit 18 demands a current I_{AnfF} for the drive motor at the time t_1. The setpoint current I_{AnfF} is designated by 66 in fig. 1. The variable power flux controller 38 applies a fuel cell demand current I_{BRZAnf} to the actuating elements of the fuel cell system 7, said current permitting the fuel cell current I_{Verf} to increase to a value $I_{BRZDynmax}$ at the time t_2 according to

the profile designated by 67 in fig. 6. Starting from the time t_2, the variable power flux controller 38 controls the fuel cell current I_{Verf} in such a way that it increases linearly, with an adjustable gradient, to the to the maximum static value $I_{BRZMaxstat}$. This value is reached at the time t_3.

From the time t_1 to t_2, the fuel cell system 7 and the dynamic power system 53 operate in the "dynamic boost" operating mode. In said mode the dynamic power system 53 is made to output a high battery current I_{Batt} which is added to the current of the fuel cell system I_{Verf}. The current I_{Batt} whose profile is designated by 68 in fig. 6 and which is generated, according to the setting of the memory element Ptn_2, with a high rate of increase which is matched to the rate of increase of the fuel cell system supplements the current I_{Verf} to form a current $I_{Fahrzeug}$ whose profile is represented by 69 in fig. 6. The dynamics of the vehicle 1 are improved by the dynamic operation with battery support.

From the time t_2 to the time t_3, the fuel cell system 7 and the dynamic power system 53 operate in the quasi-static operating mode. In this operating mode, the fuel cell system 7 is operated in a nondynamic fashion with support from the dynamic power system 53, as a result of which it is possible to save fuel. The fuel cell current I_{Verf} increases linearly, which is designated by 70 in fig. 6. The battery current I_{Batt} decreases linearly up to the time t_3. This profile is designated by 71 in fig. 6.

At the time t_3 the static operating point of the fuel cell system 7 is reached, i.e. the fuel cell current I_{Verf} has arrived at its maximum value for the respective load situation. Given a continuous demand, the fuel cell stream remains constant.

It is assumed that at the time t_4 the setpoint current

is reduced to zero by a corresponding change in the torque demand. The dynamic power system is changed over to recuperation, i.e. the power converter 3 feeds back released energy into the high voltage power system. The storage battery 10 is charged by means of the d.c./d.c. transformer 9 which is set to reverse mode. The current I_{Batt} is fed back into the storage battery 10, with limitation to $I_{Battmaxe}$. The profile I_{Batt} is designated by 72 in fig. 6. The current $I_{Fahrzeug}$ decreases in the so-called braking mode of the drive motor according to the profile designated by 73 in fig. 6. The current I_{Verf} is reduced by the variable power flux controller 38 according to the profile designated by 74 in fig. 4, in which case in addition to a very steep drop an essentially linear drop takes place up to the time t_5 at which for example the current I_{Aux} is still generated. After the decay of the current $I_{Fahrzeug}$ to zero, the storage battery 10 takes up the current which is still output by the fuel cell system 7, insofar as said current exceeds the currents of the further loads. In the way specified above it is possible to decrease the torque of the drive motor in a short time when there is a load jump from a high load point to a low load point. The excess power is stored. The chronological behavior of the torque reduction in response to the change in the setpoint value transmitter depends on the vehicle velocity (at high velocities the reduction takes place more slowly than at low velocities) and on the drive current (more slowly when there are high currents).

The adaptive flow switch compensation according to the invention improves the driving comfort and the regulating stability during operation, in particular with a high load, for example full load. In the case of fuel cells it may be necessary to reverse the direction of the gases through the cells periodically. At the changeover time there is a brief reduction in electrical power, which results in a voltage dip when

the load is constant. In a vehicle with a fuel cell the electric driving mode represents the main load. The electronic control of the electric drive must increase the power drain very dynamically when there is a voltage dip in order to maintain a constant torque. In particular when the load points are high, the power dip of the fuel cell has an adverse effect on the entire system:
The drive torque cannot always be kept constant and this results in a reduction in the driving comfort.
The electric drive has to increase its current demand very dynamically. This has a destructive effect on the process of regulating the generation of current.

The invention makes it possible to compensate power dips of the current generating system briefly. As a result, it is possible to avoid fluctuations in torque on electric drives (locomotion drive but also auxiliary drives) and thus increase the driving comfort. The process of regulating the system for generating current is improved in this way since the current demand as a result of the load (locomotive drive) does not need to be increased and there is thus no interference variable acting on the regulating process.

The adaptive flow switch compensation is carried out according to the invention in order to compensate a power dip of the fuel cell and thus prevent a voltage dip. A controlled power input from the storage battery 10 is generated as a function of the load current of the fuel cell and a flow switch information item relating to the fuel cell. A characteristic curve according to which the level of the current is dimensioned is adapted by observing the resulting voltage at the high voltage end during the flow switch compensation.

The fuel cell system signals an imminent flow switch via a logic signal. At the time of the flow switch, the

d.c./d.c. transformer is controlled as a function of the instantaneous fuel cell current in such a way that a brief current pulse is additionally input. The shape is stored in a control table and standardized to 1. The height of the pulse is dependent on the present fuel cell current and on the adaptive learning factor. The adaptive learning factor is determined continuously by observing the voltage profile when a flow switch occurs, and it corrects system-induced variation and fluctuations. If the deviations exceed a specific limit this is stored as diagnostic information.

A further essential feature of the invention is the under-voltage detection and, in conjunction therewith, an additive power input as a function of the fuel cell current by correspondingly regulating the d.c./d.c. transformer 10. In a current generating system of the fuel cell, the profile of the voltage is dependent on a very large number of factors as a function of the load current. The dependencies are currently not all capable of being described or predicted mathematically. With the under-voltage regulator according to the invention as a component of the power management system it is possible to increase the reliability and availability of the system. In addition it is possible to react actively during operation to system properties which change adversely. As a result it is possible to increase the availability of the system and determine information for service and maintenance during operation. The main function of the under-voltage regulator according to the invention is to additionally feed in power from the battery 10 when a lower limiting value of the voltage is reached. In this context, the current balance is not taken into account. The regulator output outputs an additive current demand to the d.c./d.c. transformer 9 and is dependent on the control error (ΔU) and the present load current.

A further component of the invention is a means of

detecting how frequently and in which situations the regulator must intervene, for example as a function of the load variable, temperature, air pressure, air humidity (environmental conditions). Data for service and maintenance from this information is stored. When a specific frequency value is exceeded, i.e. the regulator is >N times active per time unit, active interventions are performed in dynamics and maximum power is provided with the objective of ensuring the availability of the system. The restriction of the available power is suitably indicated to the driver.

The battery current proportion is controlled in such a way that the balancing of the current is always correct independently of changes in parameter of the overall system. The d.c. value of the drive system is of particular significance as an actual value. The necessary current proportion of the battery 10 is calculated from balancing the actual current $I_{Fahrzeug}$ and the available current of the fuel cell system I_{Verf}. As a result, the regulation concept intentionally allows for continuous infringement of the current balance.

Although the actual value has a chronological delay, this method has proven significantly more suitable than calculating the setpoint values for the battery current proportion in advance. Although at first a reaction variable (drive current) has to be present for the functioning of the method described, the method operates very effectively since the reaction time of the manipulated variable (battery current proportion controlled by means of the d.c./d.c. transformer 9) is significantly below the storage time constant of the fuel cell system (capacity of energy of the fuel cell system). The current balance of the fuel cell system 7 is as a result ensured in an optimum way. The advantages lie in a precise energy balance, which is very important in particular for reformer systems. Basically a precise energy balance in the fuel cell

system increases the efficiency and the service life of the reformer.

Given knowledge as to which quantities of energy are required with which dynamics, the dynamic power system 53 can be controlled selectively, or the power demand can be suitably adapted to the fuel cell system 7.

In the case of ABS braking the driven wheels may begin to slip. There are technical regulating methods which in such a case calculate a correction/increase torque and transmit it to the drive. In response to this, the drive usually briefly accelerates the wheels in order to decrease the slip. As a result, the wheels may, for example, increase lateral guidance again. In this case, only a small quantity of energy and a power level which can be output by a correspondingly configured dynamic power system necessary in a chronologically limited form (usually only in the case of the initiation of braking). The dynamics of the power which is made available must however be very high.

The method according to the invention is characterized in that the vehicle control unit 18 and the power control unit 19 process information or additionally acquire information themselves:

1. In the case described above the vehicle control unit feeds, for example, one bit "ABS active" to the power control unit 19. Owing to this information, the "increasing" setpoint current demand which is transferred simultaneously is not passed on to the fuel cell system 7 but instead "knows" that the demand is a short dynamic, chronologically limited demand of the vehicle control unit 18, and covers this demand best by means of a battery 10. As a result of this method, the power of the nondynamic fuel cell system 7 is not unnecessarily increased or decreased in the case of loads of this type.

2. The vehicle control unit 18 switches the time constant of the limiter of the PTn_2 element to the smallest possible value which the dynamic power system 53 can represent/follow. As a result:

- there is an improvement in the efficiency level of the fuel cell system 7 and a reduction in the consumption.
- The service life of the fuel cell system is prolonged.
- There is an improvement in the dynamics in comparison to a fixed time constant of the memory element PTn_2 which "fits the fuel cell system".
- Improvement in exhaust gas.

Further application cases or information which is processed in a suitable way are: Economy/sporty mode "information bit": Economy mode: lower power non-dynamic use of the dynamic power system. Sporty mode: opposite of the above. (Switch in the center console) stop and go mode: control determines by means of the torque data, current data, rotational speed data, velocity data and their differential quotients whether the operating mode is a stop and go operating mode (driving in a traffic jam). The power control unit 19 then sets an "average" nondynamic setpoint current demand and switches on the fuel cell system 7. The "low power" acceleration and braking processes are covered by dynamic demand levels of the dynamic power system 53. As a result:

- there is an improvement in the efficiency level, reduction in consumption,
- improvement in exhaust gas.